Howardsville to Silverton – September 1997

Study Area and Experimental Design

The tracer-injection study for Howardsville to Silverton, called the Howardsville tracer-injection study in this report, covered a 7,858 m section of the Upper Animas subbasin, starting upstream from Cunningham Gulch and the old tailings near Howardsville, and continuing to the A68 gaging station at Silverton (figs. 1 and 77). This study reach overlapped the Eureka Study reach and included several common sampling sites. This distance was divided into 40 stream segments, and there were 45 inflows sampled along the study reach (table 26). Site designations for this study reach include an H for Howardsville, followed by an S for stream sites, or an I for inflow sites and then the downstream distance at the end of each segment, or the distance of the inflow. For example, the segment that includes Cunningham Gulch is designated HS-1135 and the Cunningham Gulch inflow sample is HI-1075. Synoptic sampling sites are listed with their identifying information in table 26. Only 10 stream segments did not include inflow samples. Perhaps because of recent rains, there were many small seeps and springs along the study reach, as well as water running down from the county road along the right bank. The largest inflows included Cunningham Gulch (HI-1075), Arastra Gulch (HI-4186), an unnamed inflow at HI-1745, and Boulder Creek (HI-4951).

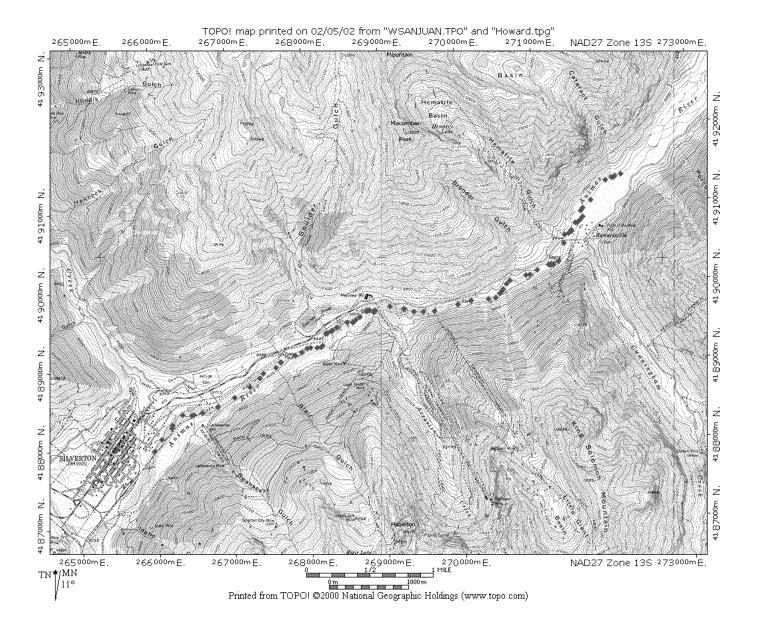| |
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| **Figure 77 near here.** |

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Table 27. Synoptic sampling sites, Upper Animas River, Eureka to Howardsville, Colorado, August 1998.

[Distance, in meters along the study reach; Q, discharge, in cubic feet per second; pH, in standard units]

Site Designation	Distance	Source	Site name	Q	pH
HS-160	160	Stream	Below injection site--replicates	39.10	7.55
HI-181	181	Inflow	Dredged ditch from Howardsville Ponds	0.05	6.92
HI-213	213	Inflow	Stream from beaver ponds	0.05	7.53
HS-310	310	Stream	Below RB ponds	39.21	7.50
HI-315	315	Inflow	RB seep from talus	0.00	7.59
HS-595	595	Stream	T1--near construction	39.21	7.40
HI-745	745	Inflow	Drains beaver pond	0.61	7.63
HI-795	795	Inflow	Outflow from cobble pond	0.61	7.36
HS-905	905	Stream	Stream ab inflow RB	40.43	7.46
HI-910	910	Inflow	From cobble road bank RB	0.37	7.65
HS-955	955	Stream	Ab Howardsville Mill	40.80	7.63
HI-965	965	Inflow	Mill Discharge (A46)	0.51	6.88
HS-1059	1059	Stream	T2--Below Howardsville Mill - verticles	41.31	7.65
HI-1075	1075	Inflow	Cunningham (A47)	13.62	8.04
HS-1135	1135	Stream	Below Cunningham	54.94	7.69
HI-1150	1150	Inflow	Hematite Guch (A48)	2.00	8.12
HS-1270	1270	Stream	Below bridge	56.94	7.64
HS-1510	1510	Stream	At State gage (A53)	57.03	7.60
HI-1605	1605	Inflow	Draining LB adit--large inflow	0.23	6.98
HI-1648	1648	Inflow	RB road bank seep (old mill site)	0.23	6.74
HI-1665	1665	Inflow	RB seep beneth old road bank	0.23	6.80
HS-1725	1725	Stream	Below clean and dirty inflows	57.70	7.58
HI-1745	1745	Inflow	Water across road RB	3.13	7.89
HS-1925	1925	Stream	At upper "campground" -- replicates	60.83	7.61
HI-2050	2050	Inflow	LB spring inflow	0.13	7.23
HS-2110	2110	Stream	Below campground	60.96	7.68
HI-2125	2125	Inflow	Drains LB ponds w/ Fe pptn	0.13	4.76
HI-2355	2355	Stream	Stream Below ponds	61.00	7.74
HI-2360	2360	Inflow	LB inflow	0.13	6.43
HI-2361	2361	Inflow	LB rapid inflow from marsh	0.13	7.30
HI-2425	2425	Inflow	Swift inflow from marshy area	0.13	7.15
HS-2515	2515	Stream	Above draining adit	61.35	7.55
HI-2522	2522	Inflow	Drains old mining	0.60	6.10
HS-2572	2572	Stream	Below adit	61.94	7.53
HI-2605	2605	Inflow	RB inflow from willows	0.01	7.92
HI-2709	2709	Inflow	RB inflow	0.01	7.92
HS-2800	2800	Stream	T3--Truck park	61.94	7.73
HS-3040	3040	Stream	Narrow chute within canyon	63.12	7.78
HI-3235	3235	Inflow	RB cascade across road	0.00	8.20
HS-3295	3295	Stream	Below first cableway	63.12	7.84
HS-3555	3555	Stream	Mid canyon	63.12	7.78
HI-3682	3682	Inflow	RB drainage off grassy hillside	0.75	8.14
HI-3820	3820	Inflow	RB cascade from rocky bank	0.75	7.93
HS-4023	4023	Stream	Between RB inflows in canyon	64.62	7.73
HI-4033	4033	Inflow	RB cascade from rocky bank	0.10	8.17
HS-4166	4166	Stream	T4 Above Arastra -- verticles	64.72	7.75
HI-4186	4186	Inflow	Arastra Gulch	7.68	7.92
HI-4190	4190	Inflow	Inflow from pipe RB	0.10	7.77
HS-4310	4310	Stream	Below Arastra	72.50	7.72
HI-4334	4334	Inflow	From "pipe bridge"	0.11	7.75
HI-4353	4353	Inflow	Stream level spring RB	0.11	4.17
HS-4473	4473	Stream	Below River Level Spring	72.73	7.68

HI-4533	4533	Inflow	Marsh area RB	0.96	4.90
HS-4581	4581	Stream	Below LB Aban. Mill	73.68	7.36
HI-4586	4586	Inflow	Ponded water RB	0.42	4.89
HS-4656	4656	Stream	Above "Pinicle Gap"	74.11	7.71
HS-4816	4816	Stream	Above Acid inflows	74.11	7.70
HI-4886	4886	Inflow	Seep w/ acid algae	0.10	5.92
HS-4916	4916	Stream	Below acid inflows	74.21	7.61
HI-4951	4951	Inflow	Boulder Creek A62	1.38	7.53
HI-4970	4970	Inflow	RB inflow-substantial	1.38	6.04
HS-5131	5131	Stream	Below Boulder Creek	76.96	7.62
HI-5161	5161	Inflow	Pond to stream LB with fish	0.50	7.47
HI-5221	5221	Inflow	Blair Gulch	0.50	7.52
HS-5306	5306	Stream	Below Blair Gulch	77.96	7.55
HI-5355	5355	Inflow	LB inflow from willow bog	0.01	6.95
HI-5356	5356	Inflow	Small ponds RB in cobbles	0.01	5.14
HI-5446	5446	Inflow	LB inflow near wells	0.01	6.72
HS-5536	5536	Stream	Below first of capped tailings	77.97	7.50
HS-5756	5756	Stream	Above drain from tails	78.84	7.42
HI-5766	5766	Inflow	Drains tailings RB in "ditch"	0.01	7.80
HI-5858	5858	Inflow	Seep along 60 m of grass	0.01	5.67
HS-6038	6038	Stream	T5--Below capped tailings	78.84	7.57
HI-6105	6105	Inflow	LB inflow from willows	0.86	7.03
HS-6288	6288	Stream	Below toe of Mayflower	79.70	7.49
HS-6528	6528	Stream	Above Lacawana Bridge	79.70	7.66
HS-6768	6768	Stream	Below Lacawana Bridge	79.70	7.65
HS-7008	7008	Stream	Above Lacawana Mill	79.70	7.69
HS-7103	7103	Stream	Discharge from Lacawana	79.70	7.61
HI-7163	7163	Inflow	Inflow LB	0.01	7.66
HS-7283	7283	Stream	Below Lacawana Mill (A66)	79.70	7.64
HI-7483	7483	Inflow	Inflow from LB	0.10	7.64
HS-7523	7523	Stream	Among braids nr town	79.70	7.63
HI-7688	7688	Inflow	RB drainage from Mayflower	0.25	7.14
HS-7858	7858	Stream	T6--At bridge / gage A68	79.95	7.63

Abandoned mines and prospects exist along the study reach; the discharge from the old mill and tailings area at Howardsville (HI-965, which was EI-6438 for the Eureka tracer injection) was one of the most visually significant for its iron staining in the stream (see Martin and others, Chapter 4G this volume). In general, the rocks on both sides of the canyon have propylitic alteration, but there also are areas of quartz-sericite-pyrite alteration (Bove and others, this volume). Stream elevation ranged from approximately 9,670 ft at the injection site to 9,300 ft at the gage. Geology of the basin is described in Yager and Bove (this volume) and Bove and others (this volume).

Results of this tracer-injection study have been reported in Paschke and others (in press). That report includes many load profiles for dissolved concentrations and also the results of solute-transport simulations. The summary here includes loading curves that are prepared using total-recoverable and dissolved concentrations. It also includes principal components analysis, which were not used in the previous study. The reader should consult Paschke and others (in press) for more details on this study.

Sodium chloride was used as the tracer for this study reach; the injectate solution had a chloride concentration of 77,760 mg/L (Paschke and others, in press). The salt was injected at a rate of 1.098 L/min, starting 1206 hours on 13 September 1997, and ran continuously until 0900 on 15 September 1997.

Discharge

The majority of background chloride concentrations were low in comparison to the injected concentrations (fig. 78). However, six inflows had chloride concentrations that were unusually high. Because these inflow concentrations were quantified, it still was possible to use equations 3 and 4 to calculate discharge. High chloride concentrations likely resulted from inflows that contained magnesium chloride salt used for dust control on the county road along the right bank. During synoptic sampling, however, chloride concentrations decreased systematically downstream from the injection, but increased in segments downstream from these high inflow concentrations (fig. 78). Discharge increased by 40.8 cfs along the study reach, and stream segments that contained sampled inflows accounted for 95 percent of this increase.

Figure 78 near here.

Figure 78. Variation of chloride and discharge with distance along the study reach,
Upper Animas River, Howardsville to Silverton, September 1997.

Cunningham Gulch (segment HS-1135) was the largest tributary inflow, accounting for

13.6 cfs, or 33 percent of the flow. Arastra Gulch (HI-4186) accounted for 7.8 cfs, which was 19

percent of the total increase. Discharge increased at segment HS-1925, perhaps more than visual

inspection of the inflow suggested it would. This increase was 8 percent of the total. Finally, there

was a 7 percent increase in the segment that included Boulder Creek (HS-5131). This included

more than just the discharge of Boulder Creek.

Characterization of Synoptic Samples

Along the study reach, pH ranged from about 7.4 to 7.8; there was no systematic

variation of pH (fig. 79a). Acidic inflows mostly occurred downstream from Arastra Gulch.

Throughout the study reach, the dominant major ions were calcium and sulfate, and their

concentrations were consistent, despite much variation among inflow concentrations (fig. 79b).

Alkalinity was less than sulfate concentration.

Figure 79 near here.
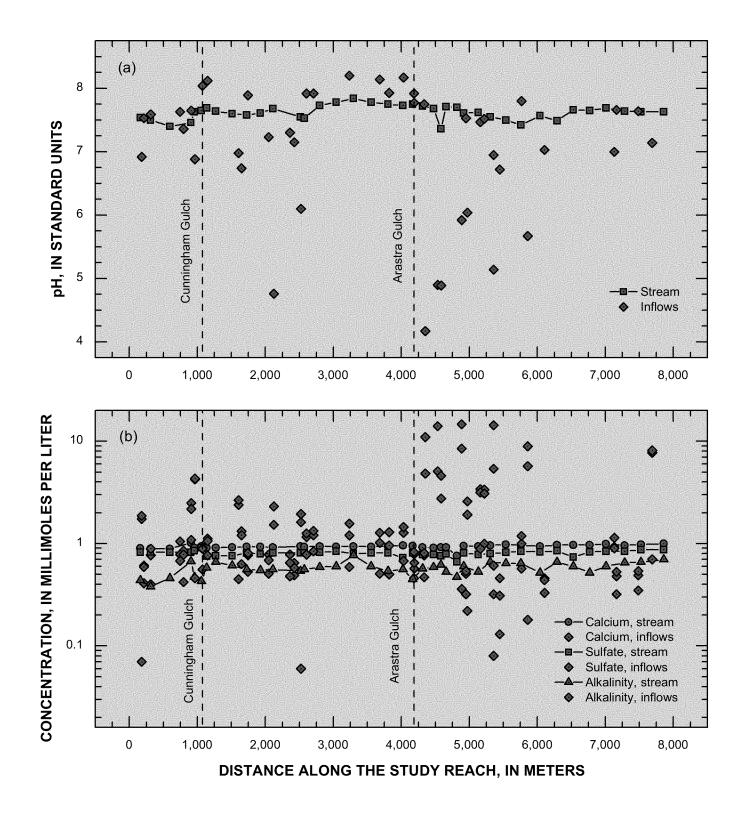
Figure 79. Variation of (a) pH and (b) calcium, sulfate, and alkalinty with distance along the study reach, Upper Animas River, Howardsville to Silverton, Colorado, September 1997.

Several metal concentrations were high (fig. 80). The highest dissolved concentrations were for manganese and zinc. Manganese concentrations ranged up to 1.10 mg/L and had a median of 0.45 mg/L. Median concentration of zinc was 0.28 mg/L (fig. 80). Colloidal concentrations of aluminum and iron also were relatively high. The colloidal concentrations were greater than dissolved concentrations, which was consistent with the relatively high pH along the study reach (figs. 79a and 80). The median concentration of colloidal iron was 0.42 mg/L; while the median dissolved concentration was 0.01 mg/L, indicating the dominance of the colloidal phase. Colloidal copper concentrations were greater than the dissolved concentration. The median concentration of colloidal zinc was 0.04 mg/L, but was lower than dissolved zinc. The majority of lead and nickel concentrations were less than detection, although colloidal lead concentrations occurred in a few samples.

Figure 80 near here.

There was a spatial pattern to the variation in concentrations manganese, zinc, colloidal aluminum, and colloidal iron. Generally, these concentrations increased downstream from the inflow at HI-965, which drains an area of old tailings, and also downstream from Arastra Gulch. There were 7 inflows downstream from Arastra Gulch that had manganese and zinc concentrations greater than 1 mg/L (figs. 81 and 82). For manganese the resulting increased concentrations in the Animas River were about 0.6 mg/L higher downstream from Arastra Gulch. The increase in zinc was only about 0.2 mg/L, but this also was substantial considering the amount of flow in the in the Animas at that point.
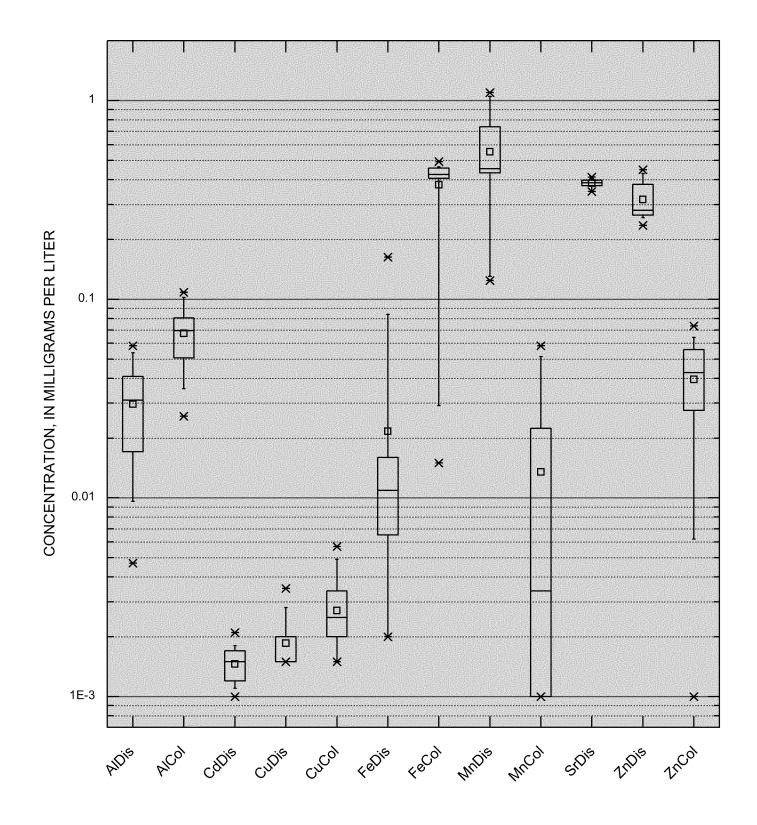

Figures 81 and 82 near here.

Figure 80. Box plot showing ranges of metal concentrations in synoptic stream samples, Upper Animas River, Howardsville to Silverton, September 1997.
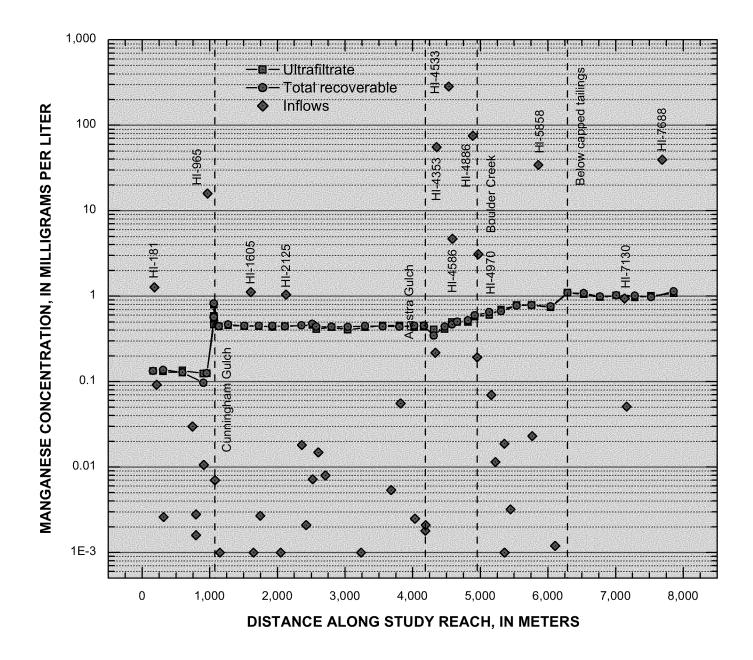
Figure 84. Variation of manganese concentration with distance in different filtrates, Upper Animas River, Howardsville to Silverton, Colorado, September 1997.
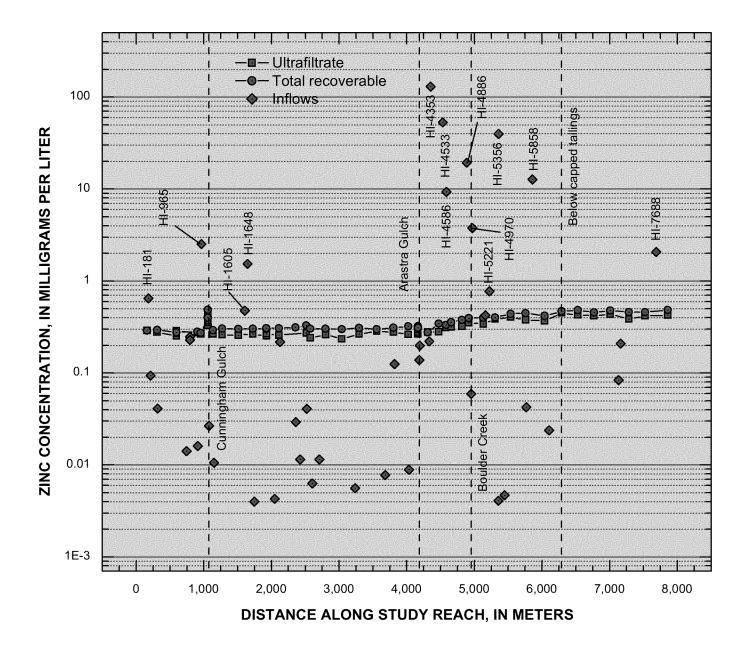
Figure 82. Variation of zinc concentration with distance in different filtrates, Upper Animas River, Howardsville to Silverton, Colorado, September 1997.

The highest inflow concentration of aluminum occurred in the discharge at HI-4353, which was a spring at stream level that was visible because of a pressure head that lifted the flow slightly above the stream level (fig. 83). Similar springs could have occurred, but were not seen during the sampling. Additional inflows downstream from Arastra Gulch also had high concentrations of aluminum, and caused the increase in total-recoverable aluminum concentration from near 0.1 mg/L to almost 0.2 mg/L. Again, this was not a large absolute increase in concentration, but was a significant change in a relatively large stream.

Figure 83 near here.

Downstream from HI-965 and Cunningham Gulch, the total-recoverable iron concentration increased and remained essentially constant, near 0.4 mg/L along the rest of the study reach (fig. 84). This inflow discharged from the area of tailings near Howardsville, and had the highest inflow concentration of iron. Other inflows that were downstream from Arastra Gulch had relatively high concentrations of iron, but these did not affect the instream concentrations. Only a small percentage of the total iron was transported as dissolved iron. The dissolved concentration of iron downstream from Cunningham Gulch progressively decreased (fig. 84). Such a decrease would be consistent with a transformation from dissolved to colloidal iron during transport.

Figure 84 near here.
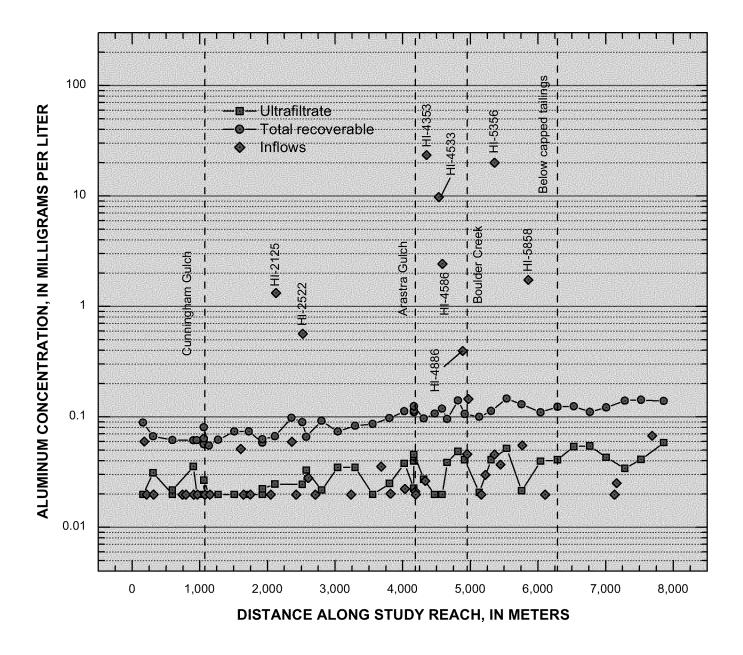

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Figure 83. Variation of aluminum concentration with distance in different filtrates, Upper Animas River, Howardsville to Silverton, Colorado, September 1997.
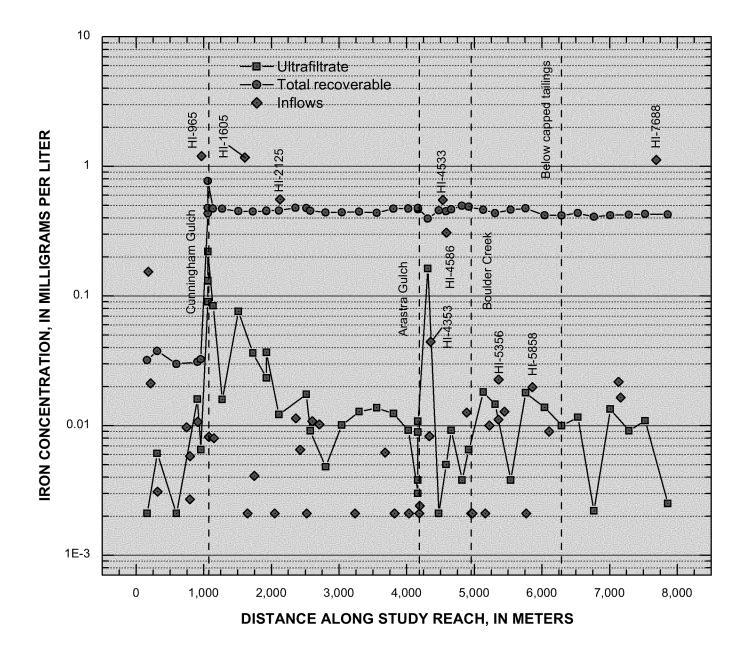
Figure 84. Variation of iron concentration with distance in different filtrates, Upper Animas River, Howardsville to Silverton, Colorado, September 1997.

When considering downstream changes among all the solutes, the PCA analysis classified all the stream samples into one group because of the large range among inflow concentrations (fig. 85). Focusing on stream sites only, however, there generally were four changes along the study reach that mostly correspond to downstream transport. The stream samples have been plotted in these four groups, labeled 1A through 1D (fig. 85). The samples upstream from the Howardsville inflow at HI-965 had the lowest concentrations (blue diamonds, fig. 85). Downstream from HI-965, iron and manganese increased substantially (green diamonds). Downstream from HS-2515, there was a shift in iron and in other metals (yellow diamonds). Finally, downstream from HS-4581 there was a continuous increase in manganese, zinc, and other metals (orange diamonds). This shift is in the direction of the inflows of group 5 that had the highest metal concentrations. The absolute change in concentration among these stream samples was not great, partly because the quantity of streamflow was substantial, but it was significant as loading profiles will indicate.

Figure 85 near here.

Inflow samples from groups 2 and 3 were are not similar to the water at the beginning of the study reach (fig. 85). Only sample HI-1648 was similar to group 1A, but generally, the chemical character of water in group 1A was a result of inflows upstream from the study reach. Changes among stream samples, from group 1A to 1C, are not in the direction of any groups of sampled inflows. This is consistent with the hypothesis that the chemistry of these upstream samples resulted from inflows that were upstream from the study reach. Other than the small shift toward inflow samples of group 5, the sampled groups of inflows did not appear to have a great affect on changes in stream chemistry.
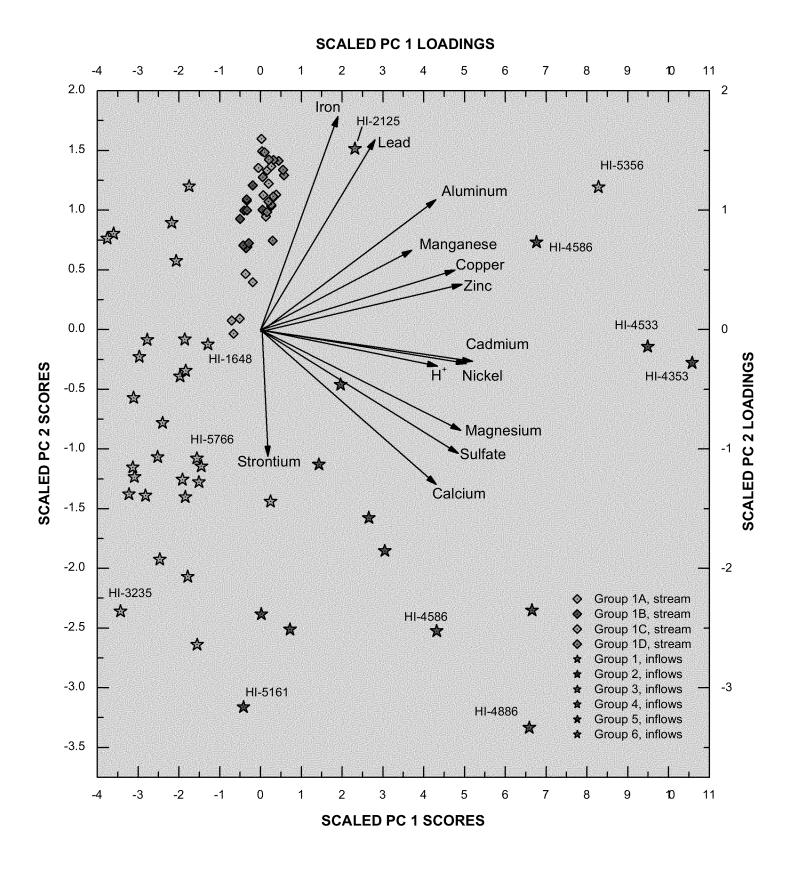
Figure 85. Biplot showing groups of inflows and stream sites, upper Animas River, from Howardsville to Silverton, Colorado, August 1997.

Table 28. Median concentrations of stream and inflow samples classified by PCA groups, Upper Animas River, Howardsville to Silverton, Colorado, September 1997.

[Dis, dissolved; Col, colloidal; pH, in standard units; all concentrations in milligrams per liter; LD, less than detection]

Solute	Phase	Group 1 All stream samples	Group 1 Mid-sulfate inflows	Group 2 High sulfate inflows	Group 3 Dilute inflows	Group 4 Acidic inflow at HI-2125	Group 5 Acidic inflows downstream from Arastra Gulch	Group 6 Inflow at HI-5356
Number of samples		39	2	8	26	1	5	1
pH	Dis	7.63	7.25	6.95	7.66	4.76	4.90	5.14
Calcium	Dis	37.6	41.9	115	34.1	61.5	204	216
Magnesium	Dis	2.55	2.14	6.51	2.12	5.80	24.4	18.0
Sodium	Dis	2.25	2.61	3.98	2.24	4.44	6.86	4.54
Chloride	Dis	1.61	4.27	0.680	0.340	0.390	2.49	1.01
Sulfate	Dis	78.1	80.5	308	48.7	222	1,050	1,380
Aluminum	Dis	0.031	0.014	0.056	0.016	1.32	2.43	20.0
	Col	0.069						
Cadmium	Dis	0.002	0.007	0.004	LD	LD	0.056	0.124
	Col	LD						
Copper	Dis	0.001	0.022	0.001	LD	0.011	0.248	2.42
	Col	0.003						
Iron	Dis	0.011	0.005	0.082	0.007	0.556	0.044	0.023
	Col	0.424						
Manganese	Dis	0.454	0.109	1.20	0.006	1.04	55.5	LD
	Col	0.003						
Nickel	Dis	LD	LD	0.004	LD	0.005	0.045	0.095
	Col	LD						
Lead	Dis	LD	0.004	LD	LD	LD	0.045	0.166
	Col	0.003						
Strontium	Dis	0.385	0.547	0.848	0.358	LD	1.23	LD
Zinc	Dis	0.281	0.88	0.713	0.020	0.218	19.4	39.8
	Col	0.043						

Load Profiles

Load profiles quantify physical and chemical changes along the study reach, and help to indicate whether changes result from dilution or chemical reaction. A summary of load calculations for the Howardsville study reach is listed in table 28. There were some special considerations for these calculations. First, at HS-4581, the calculated inflow load greatly exceeded the increase in sampled instream load for most all the metals. Considering this large inflow load, it is unlikely that the sampled inflow was representative of the water entering the Animas River in that stream segment. Because that sampled inflow did not appear to affect the instream load, the inflow load for that stream segment was assumed to be equal to the instream load.

Second, most of the aluminum concentrations along the study reach were in a poor analytical range for the ICP-AES analysis. It was possible to determine the trend of aluminum concentrations by smoothing the data after the method of Velleman and Hoaglin (1981). Greater analytical variability for all the metals required some smoothing, but not to the extent that was necessary for aluminum. The effect of smoothing is to eliminate small increases to the cumulative instream load that most likely do not represent real increases in load.

Table 29. Summary of load calculations for selected metals, upper Animas River, Howardsville to Silverton, Colorado, September 1997.

[All loads are in kilograms per day; red text with parentheses indicates a negative net load for a stream segment; magnitude of loads are indicated by colors; red, greatest or first; orange, second; yellow, third; green, fourth; and blue, fifth]]

Site Description	Distance	Aluminum	Cadmium	Copper	Iron	Manganese	Lead	Strontium	Zinc	Sulfate
Below injection site	160	4.19	0.127	0.240	2.20	8.54	0.160	23.6	18.9	5260
Stream at 310 m	310	0.015	0.000	0.001	0.008	0.031	0.001	0.087	0.069	19.3
T1--near construction	595	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Stream Above inflow RB	905	0.046	0.001	0.003	0.024	0.094	0.002	0.260	0.207	57.8
Above Howardsville Mill	955	0.046	0.001	0.023	0.024	0.094	0.002	1.07	0.207	245
T2--Below Howardsville Mill	1059	0.327	0.001	0.031	36.6	32.6	0.002	0.474	10.4	438
Below Cunningham	1135	1.09	0.067	0.131	10.6	6.43	0.085	13.3	2.03	1610
Below bridge	1270	0.752	0.000	(0.073)	(0.219)	0.000	0.000	0.282	0.000	0.000
At State gage (A53)	1510	0.676	0.000	(0.020)	(1.96)	(0.866)	0.001	0.259	0.074	17.9
Below clean and dirty inflows	1725	0.176	0.002	0.004	1.06	0.373	0.003	0.650	0.372	534
At upper "campground"	1925	0.477	0.011	0.018	2.48	2.40	0.013	2.20	1.71	435
Below campground	2110	0.109	0.000	0.023	0.056	(0.043)	0.001	0.093	0.074	18.9
Stream at 2515 m	2515	0.292	0.001	0.038	0.255	3.75	0.339	0.970	2.98	56.7
Below adit	2572	0.498	0.002	0.016	0.227	(3.35)	0.007	0.471	(1.94)	94.5
T3--Truck park	2800	0.283	0.001	0.012	(0.284)	(0.013)	0.003	0.188	0.151	178
Narrow chute within canyon	3040	0.287	0.003	0.010	0.426	0.481	0.008	0.565	0.452	326
Below first cableway	3295	0.326	0.000	(0.017)	0.224	1.20	0.000	0.000	0.000	(295)
Mid canyon	3555	0.693	0.000	0.000	0.000	0.867	0.000	0.000	0.000	0.000
Stream at 3802 m	3802	1.91	0.015	(0.155)	5.76	3.14	0.042	2.97	2.38	601
Between RB inflows in canyon	4023	1.89	0.015	0.018	4.25	3.43	0.043	3.05	2.44	616
T4 Above Arastra	4166	0.445	0.000	0.026	(0.010)	(0.588)	0.000	0.000	0.000	0.000
Below Arastra Gulch	4310	1.79	0.031	0.925	(3.31)	1.56	0.087	7.08	0.623	782
Below River Level Spring	4473	0.054	0.060	(0.543)	9.39	5.01	0.274	(0.356)	8.00	91.2
Below LB Abandoned Mill	4581	0.217	0.004	(0.140)	1.42	9.43	0.271	1.04	2.50	147
Above "Pinicle Gap"	4656	0.108	0.002	0.004	1.71	1.12	0.983	0.531	2.28	185
Above Acid inflows	4816	0.000	0.000	0.000	4.12	3.08	(0.754)	0.226	3.18	0.000
Below acid inflows	4916	0.000	0.000	0.000	(1.25)	11.5	0.000	0.483	2.59	0.000
Below Boulder Creek	5131	0.623	0.013	0.021	(1.85)	11.7	(1.021)	2.63	2.58	426
Below Blair Gulch	5306	0.956	0.003	0.005	0.562	7.51	0.004	2.43	1.10	323
Below first of capped tailings	5536	0.987	0.000	0.000	0.647	14.6	0.000	0.410	6.25	325
Above drain from tails	5756	2.29	0.036	0.272	9.23	12.3	0.055	5.53	7.98	1410
T5--Below capped tailings	6038	0.000	0.000	0.110	(9.60)	0.000	0.589	0.000	0.000	0.000
Below toe of Mayflower	6288	1.61	0.067	0.174	6.15	68.3	0.089	5.27	10.1	1340
Above Lacawana Bridge	6528	1.92	0.059	0.136	5.70	13.8	0.106	6.27	7.24	868
Below Lacawana Bridge	6768	0.000	0.020	(0.163)	(0.001)	(18.4)	0.000	0.000	0.000	0.000
Above Lacawana Mill	7008	0.061	0.022	(0.137)	0.492	6.67	0.003	0.199	0.230	168
Below Lacawana Mill (A66)	7283	1.90	(0.081)	0.000	0.449	(1.86)	0.000	0.303	0.000	26.3
Among braids nr town	7523	1.03	(0.079)	0.004	0.721	0.926	0.005	0.787	0.345	680
T6--At bridge / gage A68	7858	0.212	0.000	0.101	0.155	25.2	0.000	2.01	0.000	(114)
Cumulative instream load		28.3	0.57	2.31	105	256	3.18	85.8	97.39	17300
Cumulative inflow load		15.1	0.46	1.73	6.37	72.0	1.13	64.9	81.57	12900
Percent inflow load		53%	81%	75%	6%	28%	36%	76%	84%	75%
Unsampled inflow		13.2	0.11	0.58	98.50	184.09	2.04	20.88	15.81	4400
Percent unsampled inflow		47%	19%	25%	94%	72%	64%	24%	16%	25%
Attenuation		0.00	0.16	2.2	18.5	25.1	1.8	0.4	2.0	400
Percent attenuation		0%	28%	95%	18%	10%	56%	0%	2%	2%

Load profiles for selected solutes indicate similarities and differences in patterns of loading and in the reactive nature of the solutes. Several solutes had substantial loads at the beginning of the study reach. Strontium (fig. 86) had 28 percent of its cumulative instream load, and sulfate (fig. 87) had 33 percent in the first stream segment. This indicates that there were sources upstream from the study reach. Cadmium (fig. 88), zinc (fig. 89), and aluminum (fig. 90) each had from 15 to 22 percent from upstream. Each of these solutes, except aluminum and cadmium, gained a substantial amount of load from the inflow at HI-965. Iron (fig. 91) gained 37 percent of its load from that inflow.

Figures 86-91 near here.
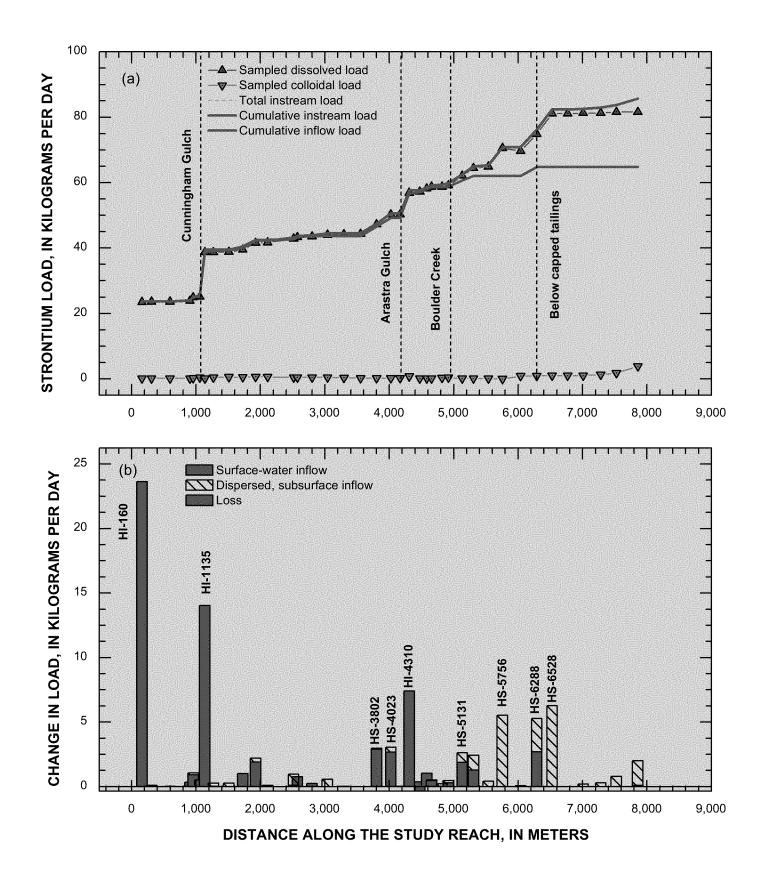
Figure --. Variation of (a) strontium load with distance along the study reach and (b) change in load for individual stream segments.
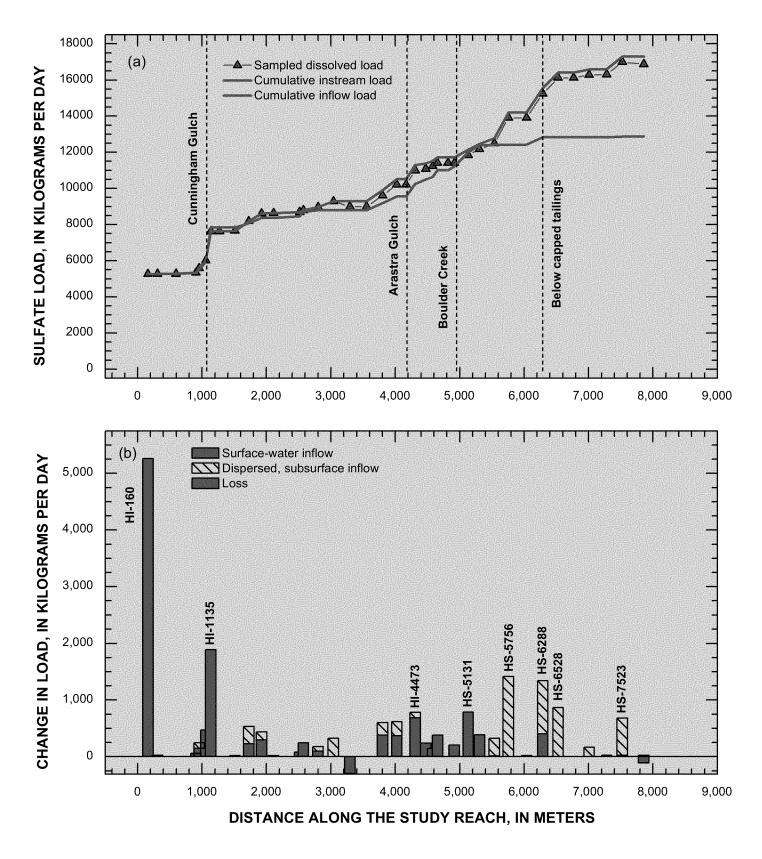
Figure --. Variation of (a) sulfate load with distance along the study reach and (b) change in load for individual stream segments.
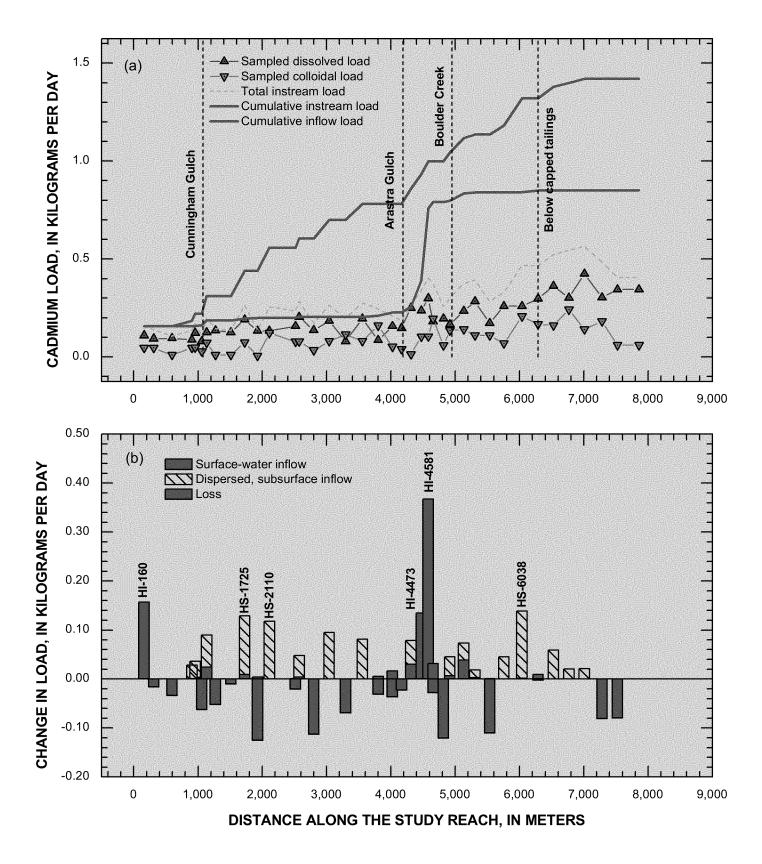
Figure --. Variation of (a) cadmium load with distance along the study reach and (b) change in load for individual stream segments.
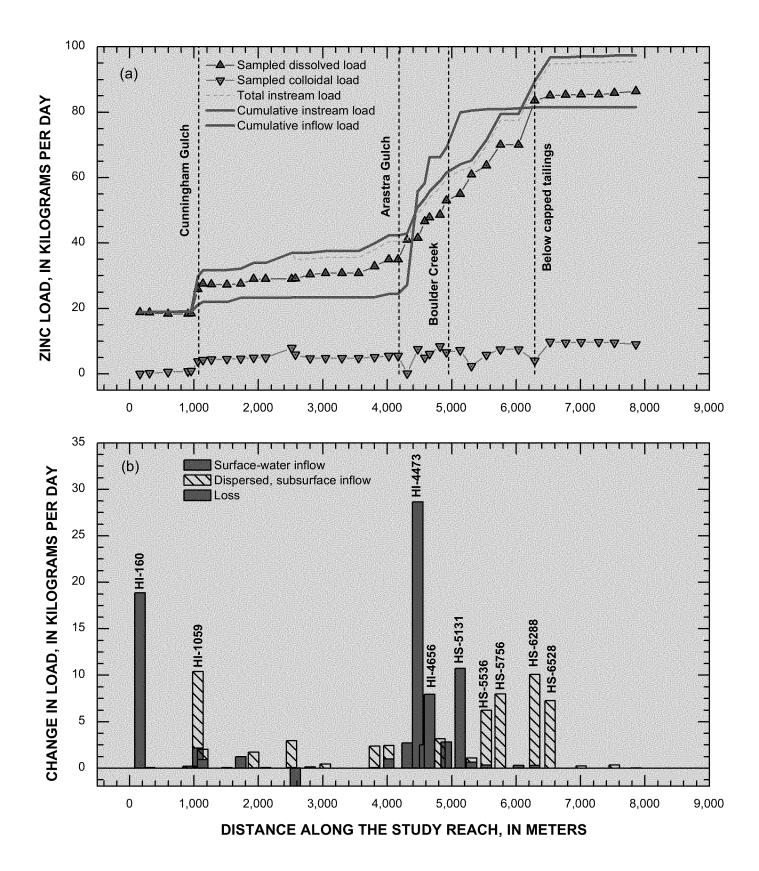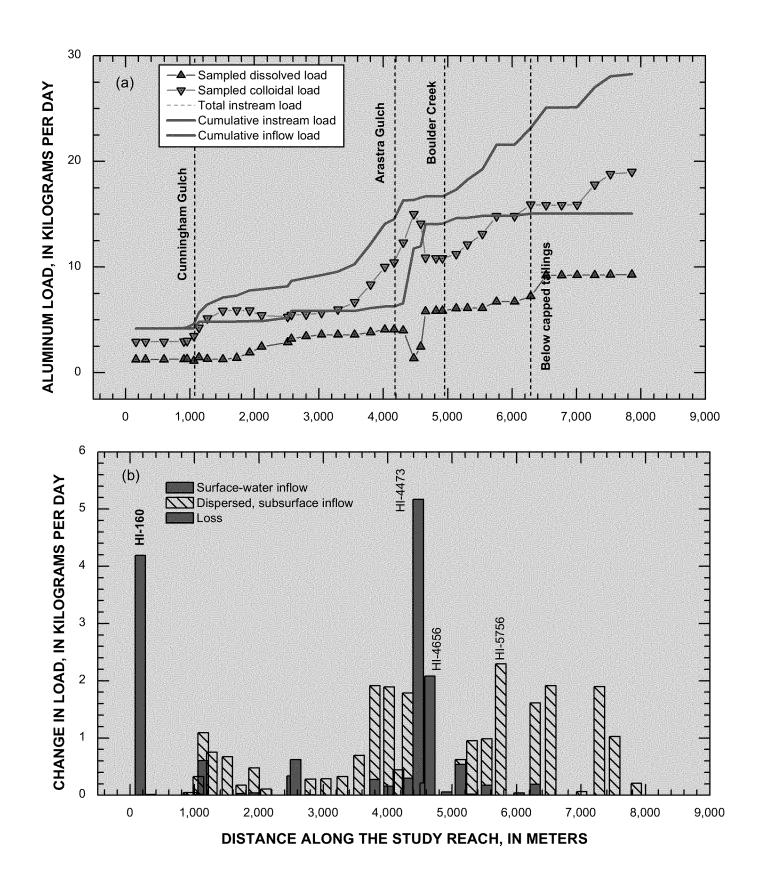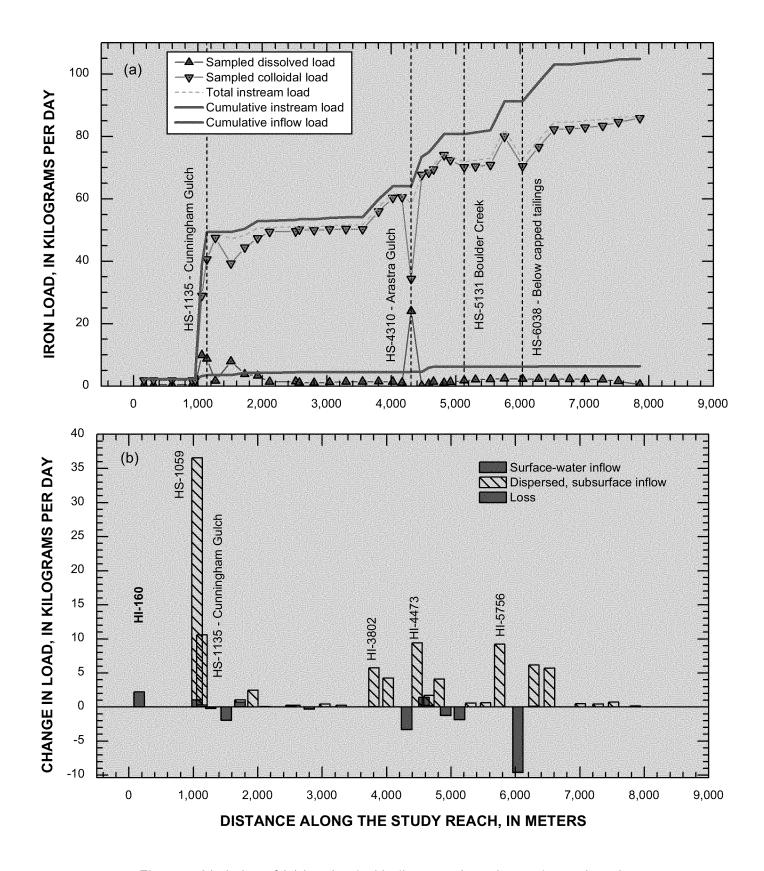
Figure --. Variation of (a) zinc load with distance along the study reach and (b) change in load for individual stream segments.

Figure 86. Variation of (a) aluminum load with distance along the study reach and (b) change in load for individual stream segments.

Figure --. Variation of (a) iron load with distance along the study reach and (b) change in load for individual stream segments.

Manganese (fig. 92) typically is very similar to zinc, but in this study reach, there were differences in their sources. As noted, loading of zinc was substantial upstream of the study reach and from HI-965 (fig. 89). There was a substantial load of manganese at HI-965, but the greatest load of manganese occurred downstream in segment HS-6288.

Figure 92 near here.

Patterns of copper (fig. 93) and lead (fig. 94) were different from all the others because these metals were very reactive. Both metals had their greatest load in the section of the study reach downstream from Arastra Gulch; copper in HS-4310, and lead in HS-4656.

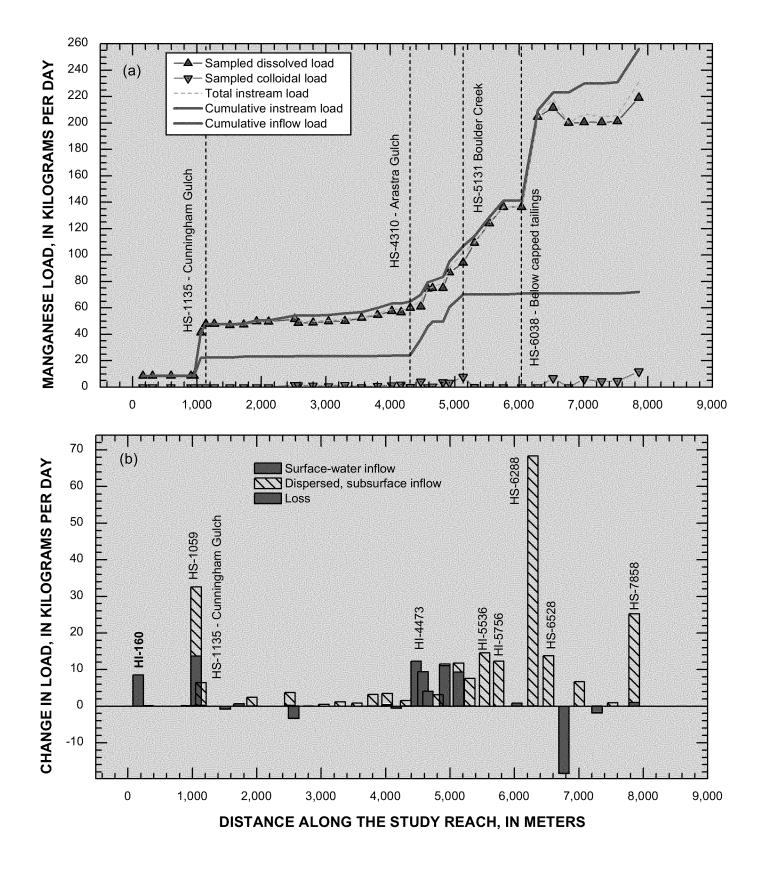**Figures 93 and 94 near here.**

Figure --. Variation of (a) manganese load with distance along the study reach and (b) change in load for individual stream segments.
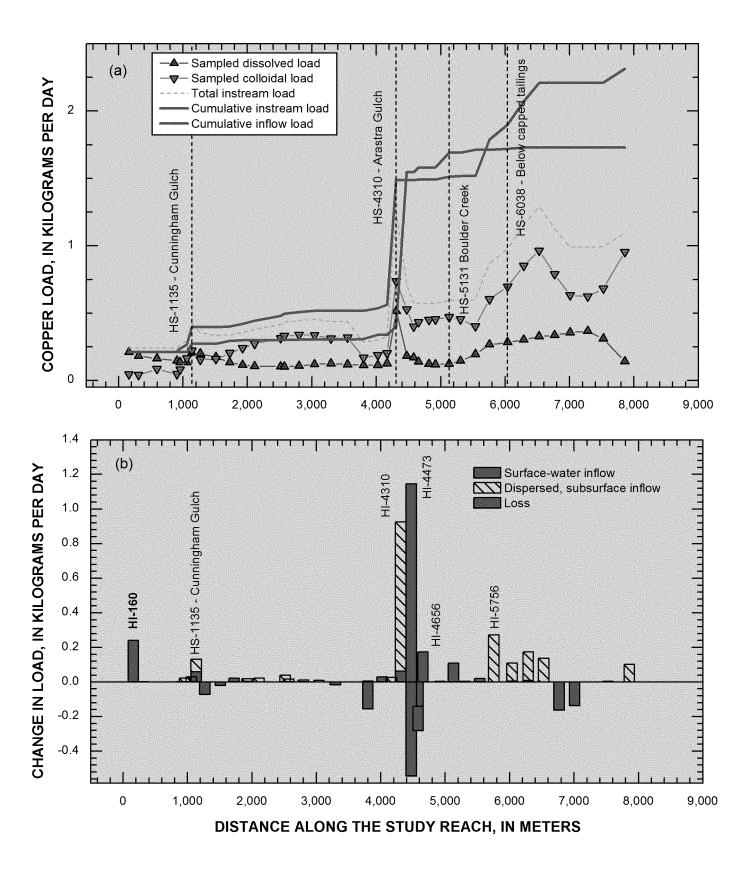
Figure --. Variation of (a) copper load with distance along the study reach and
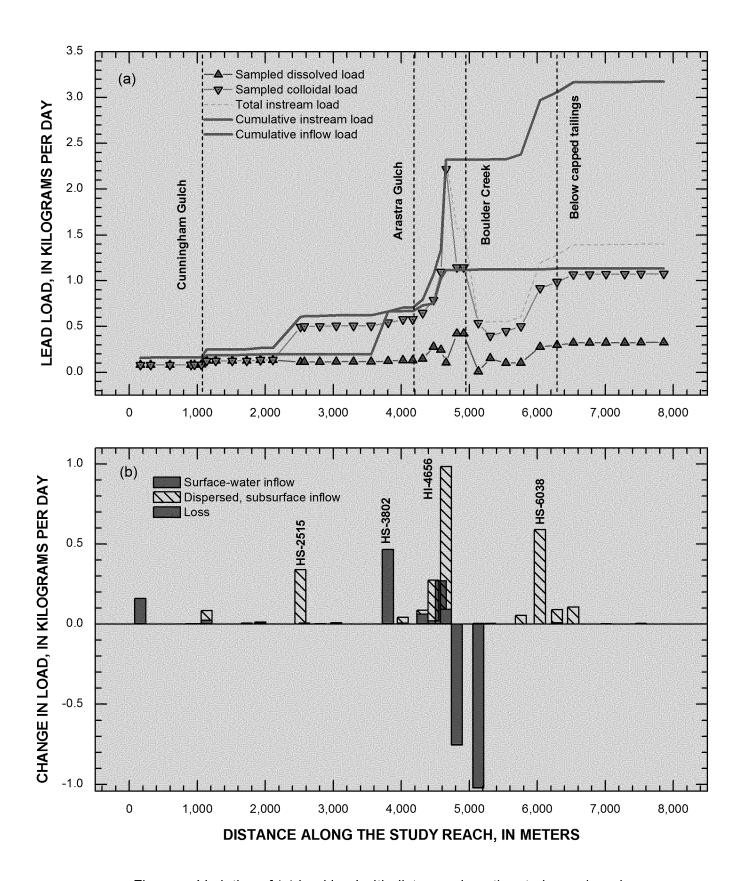(b) change in load for individual stream segments.

Figure --. Variation of (a) lead load with distance along the study reach and (b) change in load for individual stream segments.

Principal sources of metal load

There greatest loads from individual stream segments are indicated in table 28. The colors give a visual pattern of those areas where the loading occurs. These areas include:

1. Upstream from the study reach (HS-160) -- Strontium, sulfate, cadmium, and zinc had substantial sources upstream from the study reach.

2. Area of old tailings near Howardsville (HI-965) – Iron, manganese and zinc were all added with this inflow. There was a prominent iron stain along the left bank of the stream downstream from the inflow, indicating the iron-rich water.

3. Cunningham Gulch (HI-1075)– Iron, strontium, and sulfate were added by the inflow of Cunningham Gulch. There are sources of metals upstream in Cunningham Gulch (Herron and others, xxxx), but this most likely represents weathering of non-sulfide minerals.

4. Downstream from Arastra Gulch (HS-4310 through HS-6528) – Copper and lead were the principal metals added in these segments. Iron and strontium also had loads in segments HS-4473 and HS-4310, respectively.

5. Downstream from Blair Gulch to Lacawana Bridge (HS-5536 through HS-6528) – Each of the metals had some loading in these segments. This was the location for the greatest loading of manganese.

6. Ditch draining right bank near Silverton (HS-7858) – Copper and manganese increased in the last stream segment where a ditch enters the stream. The source of metals to the ditch is not clear, but could include buried tailings or waste rock in the alluvium of the Animas River.

Unsampled inflow

There was a very noticeable change from sampled to unsampled inflow along the study reach. The change was downstream from Arastra Gulch, and mostly included inflows to stream segments between Arastra Gulch and Lacawana Bridge. The source of metals in this reach of the stream has not been determined. Possibilities include drainage of the Mayflower tailings piles and alluvial tailings. Seeps along the right bank that have iron and aluminum precipitates have been observed at a lower stage of the river than the time of the tracer study (T. Nash, 2001, U.S. Geological Survey, written communication). Considering the relatively high flow of the Upper Animas River compared to other streams in this study, the small increases in concentration represent a substantial increase in metal load.

Attenuation

For most metals, there was not much attenuation along the study reach from Howardsville to Silverton. Only the decreases for cadmium, copper, and lead loads were substantial. Both copper and lead increased greatly in the area downstream from Arastra Gulch. After this increase, most of the load that had come into the stream was removed from the stream. There was some loss of iron load in segment HS-4310, and the largest decrease in copper load occurred in the next segment downstream, suggesting that the copper loss could be related to the loss of iron colloids. The attenuation of lead load was greatest in segment HS-5131, downstream from Boulder Creek, and this also corresponded to a loss of iron load.